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Biomass fuel combustion and health*

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Biomass fuels (wood, agricultural waste, and dung) are used by about half the world's population as a major, often the only, source of domestic energy for cooking and heating. The smoke emissions from these fuels are an important source of indoor air pollution, especially in rural communities in developing countries. These emissions contain important pollutants that adversely affect health—such as suspended particulate matter and polycyclic organic matter which includes a number of known carcinogens, such as benzo[a]*pyrene, as well as gaseous pollutants like carbon monoxide and formaldehyde.*

Exposure to large amounts of smoke may present a health risk that is of a similar order of magnitude to the risk from tobacco smoke. The effects on health arising from exposure to air pollution are reviewed, based on what has been reported in the literature so far. Further and more detailed information on exposures and on the epidemiological aspects is urgently required.

The persons most frequently affected are women who do the cooking for households in rural villages; they suffer from impaired health due to prolonged and repeated contact with these harmful pollutants. When they are pregnant, the developing fetus may also be exposed and this leads to the risk of excess deaths. In the developing countries, exposure to biomass fuel emissions is probably one of the most important occupational health hazards for women. A conservatively estimated 300–400 million people worldwide, mostly in the rural areas of developing countries, are affected by these problems.

To many people air pollution is associated only with urban combustion of fossil fuels in industrial countries where the high level of economic development has led to a high consumption of energy per capita. The present review, however, is directed at the opposite situation: rural agricultural communities in the developing countries, where biomass is the principal fuel and where both income and energy consumption are among the lowest in the world.

The principal biomass fuels are wood, crop residues or agricultural waste, and manure (*1*), the last coming mainly from domesticated animals such as cows. These fuels are composed of complex organic matter—vegetable proteins and carbohydrates incorporating carbon, nitrogen, oxygen, hydrogen, and certain other elements in trace amounts. Their combustion often produces substances harmful to human health, such as a range of polycyclic hydrocarbons not found in the fuels themselves.

This review discusses the broad question, "What is the severity and extent of health problems associated with pollution from biomass combustion in the rural areas of developing countries?" To deal with this question, certain issues are examined that do not fit neatly into traditional disciplines of inquiry. They could be classified as problems concerned with economic development, environment, energy, housing, and health, to

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Table 1. Global energy consumption in 1982 (million metric tons coal equivalent)

Item	Developing countries	Developed countries	Total
Population (millions)	3400	1200	4600
Modern fuels			
Petroleum	1030	3200	4230
Coal	1025	2025	3050
Natural gas	235	1735	1970
Hydropower	177	500	677
Nuclear power	8	315	323
Subtotal	2475	7775	10250
(Per capita in kg)	(720)	(6750)	(2230)
Biomass fuels			
Fuelwood	460	225	685
Crop residues and others	340	15	355
Animal dung	100	low	100
Subtotal	900[a]	240[b]	1140
(Per capita in kg)	(260)	(210)	(250)

[a] The consumption of biomass fuels is uncertain and estimates for fuelwood are likely to be substantially understated. Energy equivalents for biomass fuels are situation specific and global averages are uncertain.

[b] Calculated from US data assuming that the rest of the developed world uses biomass fuels in the same ratio relative to their commercial energy use (USA is 35%).

(Source: United Nations and U.S. Departments of Energy and Interior.)

name a few of the most obvious. Like the causes, the solutions too are not simple because they must deal with a range of social and technical problems if they are to be feasible and effective.

GLOBAL PATTERNS OF FUEL USE

As shown in Table 1, the total energy obtained from biomass is small compared with that supplied by fossil fuels, although it exceeds the energy provided by nuclear power and hydropower. These biomass fuels are used largely in the developing countries and predominantly in the rural areas.

Although biomass fuels today supply a relatively small fraction (10%) of the global energy requirements in terms of total energy content, they provide the largest fraction of energy in terms of the number of people using them. As shown in Fig. 1, most of the people in the world depend on these traditional fuels for most of their energy supply. Even today, most of this fuel is used for the same tasks for which it has traditionally been needed— namely, for cooking and space heating. It is estimated,

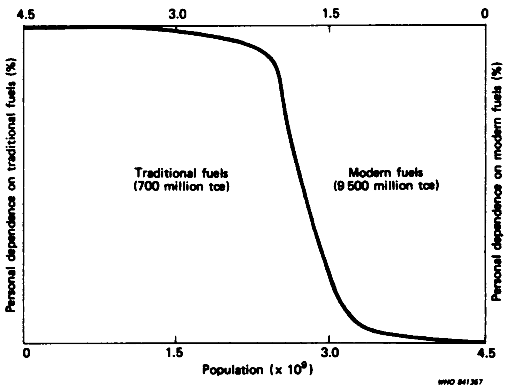

Fig. 1. Global personal use of traditional and modern fuels, based on data for 1982. (Note: the figures and position of the curve are approximate; tce = metric tons coal equivalent.)

Table 2. Principal cooking fuels in the world: estimates of the percentage of the population relying principally on each fuel in 1976

	Commercial fuels (%)	Wood fuels (%)	Dung and crop residues (%)	Total population (millions)
Developing Asia	19	48	33	1935
India	10	48	43	610
Urban non-poor	67	33	low	60
Urban poor	low	57	43	70
Rural	4	48	48	480
Rest of South Asia	12	46	41	205
Urban non-poor	75	25	low	20
Urban poor	low	67	33	15
Rural	6	47	47	170
East Asia and Pacific				
Urban non-poor	73	27	low	55
Urban poor	50	50	low	30
Rural	22	44	33	180
Centrally planned economies in Asia	22	51	27	855
Urban	73	27	low	205
Rural	6	58	35	650
Africa, south of Sahara	10	63	26	340
Urban non-poor	83	17	low	30
Urban poor	low	100	low	20
Rural	3	66	31	290
North Africa and Middle East	53	18	3	200
Urban non-poor	100	low	low	70
Urban poor	50	50	low	20
Rural	23	23	55	110
Latin America and Caribbean	71	26	3	325
Urban non-poor	100	low	low	145
Urban poor	50	50	low	50
Rural	46	46	8	130
Total developing countries	26	45	28	2800
Developed countries (including eastern Europe and USSR)	100	low	low	1105
World	47	32	20	3905

(Source: modified from reference *2*)

for example, that about half the world's households cook daily with biomass fuels. From Table 2, it may be deduced that approximately 30% of urban households and 90% of rural households in developing countries rely on biomass fuels for cooking (*2*). In these countries, cooking stoves are often inefficient in terms of usable thermal output; often only

10–15% of the energy potential is utilized by such stoves (*3*). Combustion, especially when it is inefficient, produces considerable amounts of smoke particles as well as gaseous products, often with no exhaust to the outside. If, as is often the case, there is poor ventilation, indoor air pollution can be very severe.

There is great variation in housing styles and construction, and in cooking methods and practices in the developing countries; but crowding, proximity of infants and children to the cooking area, use of low-efficiency stoves, long hours spent at these stoves, and poor ventilation are common factors. More than two-thirds of the households in the world lie in developing countries and about three-quarters of these are in rural areas. Thus, the most prevalent indoor environment today is the same one that has dominated most of human history—huts in rural communities (*4*). The health hazard associated with the use of biomass fuels by such large numbers of people must be controlled if the goal of health for all by the year 2000 is to be achieved.

SOURCES AND EMISSIONS OF AIR POLLUTION

There are a number of ways to categorize cooking stoves. For some inquiries, it may be appropriate to categorize them by construction material, by the number of pots that can be placed on them, or by efficiency. With regard to smoke emissions, perhaps the best categories are those relating to the design of the combustion chamber. Although there are many variations, four models seem to stand out:

(*a*) Open combustion with no combustion chamber at all. Three rocks or bricks for holding the pot above an open fire is the most common example of this type. This arrangement is obviously the cheapest possible and is thus used by the poor in all countries.

(*b*) Partly open combustion. Either by digging a shallow pit in the ground or by making a U-shaped hole in a block of clay or bricks, a semi-enclosed combustion chamber is created.

(*c*) Enclosed chamber with no flue. These stoves are made from clay or metal, or are dug into the ground, and have an enclosed combustion chamber but no chimney for inducing natural drafts or for removing smoke. Examples are the Thai bucket stove, the ordinary and improved clay stoves of Pondicherry (India), and the deep pit stove much used in Bangladesh.

(*d*) Enclosed chamber with a flue. These stoves rely on a chimney to create a natural draught through an enclosed combustion chamber and also remove the smoke from the room. Examples are the well-known Magan, Hyderabad, Singer, and Lorena smokeless cooking stoves, the first two having been developed in India, the last two in Indonesia and Guatemala respectively.

Biomass fuels include a wide range of materials in different physical forms. Crop residues such as cotton stalks, oilseed stalks, rice straw, and coconut husks make important contributions, as do dried dung from large animals such as cattle, buffalo, and camels. Scrub plants, weeds, cactus, and other miscellaneous forms of biomass are also used. The most important form, of course, has always been wood. Fuelwood, however, is also a heterogeneous category. Logs, branches, bark, twigs, and leaves each have different chemical and physical characteristics to some extent, as do samples from different species.

The pattern of biomass usage varies dramatically with local conditions. In some areas, there is little seasonal variation and only wood—often of many species—is used, e.g., in the highlands of Papua New Guinea. In other areas, a single species grown in fuelwood plantations is marketed essentially to the exclusion of other varieties, e.g., the casuarina plantations of Pondicherry, India. In some areas, the pattern changes with the seasons;

Table 3. Variety of traditional biomass fuels in Uttar Pradesh, India

Village	Families	Population	Quintals/month[a]				
			Crop residues	Fuel-wood	Leaves and spring plants	Dung	Total
Eastern Plain Region							
Patharhat	202	1394	27.0 (3.8)[b]	334.1 (46.5)	104.7 (14.6)	253.3 (35.2)	719.2 (100.0)
Hariharpur	73	648	29.7 (8.2)	102.4 (28.2)	10.7 (2.9)	220.3 (60.7)	363.1 (100.0)
Hazipur	59	332	—	21.4 (15.7)	37.7 (27.6)	77.3 (56.7)	136.4 (100.0)
Bundelkhand							
Pindari	138	863	177.4 (31.6)	5.2 (0.9)	35.1 (6.3)	343.2 (61.2)	560.9 (100.0)
Naraich	58	289	74.5 (27.3)	35.8 (13.1)	18.4 (6.7)	144.3 (52.9)	273.0 (100.0)

[a] 1 Quintal = 100 kg

[b] Figures in parentheses are percentages.

(Source: See footnote *a* below.)

Table 4. Estimated annual consumption of energy in 1980 from different sources in Madagascar (in thousands of equivalent tons of petrol (ETP × 10^3))

	Domestic	Industrial	Transport	Total
Wood and derivatives	622.5 (92)[a]	9.5 (7)[a]		632 (61)[a]
Agricultural by-products and wastes	0.3 (–)	6 (4)		6.3 (–)
Petroleum products	45 (7)	95 (67)	212.4 (100)	352.4 (34)
Coal		13 (9)		13 (1)
Hydro-electricity	10.2 (1)	18.8 (14)		29 (3)
Total	678 (100)	142.3 (100)	212.4 (100)	1032.8 (100)

[a] Figures in parentheses are percentages. The – sign means percentage is less than 1.

(Source: See footnote *b* below.)

mainly wood at one season, crop residues at other times, e.g., in parts of northern India. Some coastal areas of Sri Lanka rely mostly on coconut residues (husks, shells, and fronds). The variation is thus wide and generalizations are difficult. Even within a single area, the variations can be large because of local differences in income and land availability. Table 3, for example, shows the variation among five villages in adjacent districts in Uttar Pradesh, India.[a] Table 4 shows another example of energy derived from different sources in Madagascar.[b]

In general, it is fair to say that the 50% or more of the world's households cooking with biomass fuels use approximately 1 kg of fuelwood equivalent per person-day (approximately 15 MJ heat content). More is used, of course, where space heating, or other needs such as bath water, fodder preparation, and alcoholic beverage manufacture are met by

[a] AGRAWAL, S. C. *Rural energy system in two regions of Uttar Pradesh, India: first phase report.* Unpublished document ERD-PR-1-81. Resource Systems Institute, East-West Center, Honolulu, 1981.

[b] *A brief report on the use of biomass fuels and public health in Madagascar.* WHO unpublished report MAD/BSM/001/84.1, Brazzaville, 1984.

Table 5. Comparison of air pollutant emissions from energy-equivalent fuels (in kilograms)[a]

Fuel	Fuel equivalent to one million megajoules delivered	Suspended particulate matter	Sulfur oxides	Nitrogen oxides	Hydrocarbons	Carbon monoxide
Industrial						
Wood (70%)[b]	80 metric tons	480	56	360	360	400
Coal (80%)	43 metric tons	2080	810	1180	6	45
Residual oil (80%)	33 000 litres	94	1310	240	4	20
Distillate oil (90%)	31 400 litres	8	1210	83	4	19
Natural gas (90%)	28 200 cubic metres	7	Neg.	99	2	8
Residential						
Wood (40%)[b]	144 metric tons	2170	86	110	1450	18790
Coal (50%)	69 metric tons	520	1200	270	430	2380
Distillate oil (85%)	32 900 litres	11	1170	71	4	20
Natural gas (85%)	30 000 cubic metres	7	Neg.	38	4	10

[a] The figures in this Table are typical, not average, figures. Actual efficiencies and emissions depend on fuel quality and combustion conditions. Residential heating stoves under US conditions.

[b] The figures in parentheses are the percentage efficiency of the fuel.

(Source: with modifications from reference *6*).

biomass fuels. Less is used by the very poor.

It is interesting to note that this is approximately equal to the energy used per capita for household cooking in the USA (*5*). This reflects partly the commercial pre-processing of food in developed countries but also the relative inefficiency of primary energy use in traditional stove/fuel combinations. Total utility, of course, is a function also of operating ease, reliability, comfort, and other variables that may be affected adversely by single-minded efforts to enhance energy efficiency or reduce emissions.

When incomplete combustion occurs in small fires, the air pollution can increase dramatically. Table 5 shows some typical values, which can be compared directly with those of large-scale industrial combustion (*6*). Listed in the Table are five principal air pollutants for which many nations have set standards. Note that biomass combustion produces relatively high amounts of three pollutants: suspended particulate matter, hydrocarbons, and carbon monoxide. By comparison, biomass combustion is not a principal source of sulfur or nitrogen oxides. The dramatic increase in suspended particulate matter (SPM) is the result of the production, by incomplete combustion, of a mixture of soot and those hydrocarbons commonly called creosote and tars. Of critical importance also is the size distribution of the SPM from biomass combustion. Nearly all the particles are below 3 μm in diameter and thus can be considered to be respirable, i.e., able to penetrate and be deposited deep in the lung.[c]

HEALTH EFFECTS

Acute effects on health are the result of smoke inhalation and of carbon monoxide poisoning; both are life-threatening and cause rapid death if sufficient concentrations occur in the respired air. Subacute effects are the result of the irritant or inflammatory action of the pollutants on the conjunctiva and the mucous linings of the respiratory tract

[c] SMITH, K. K. ET AL. *Carbon monoxide and particulates from cooking stoves: results from a simulated village kitchen.* Paper presented at the Third International Conference on Indoor Air Quality, Stockholm, 20-24 August 1984.

from the nose to the bronchi. Several pollutants in biomass fuel emissions such as aldehydes, phenols, and toluene are among the important hydrocarbons that have an irritant action.

It becomes difficult to draw a distinction between acute and subacute effects when considering the natural history of respiratory disease in infants and small children exposed to wood smoke. The subacute inflammatory reactions caused by recurrent exposure to irritant and cilia-toxic and mucus-coagulating emissions make the trachea, bronchi, and bronchioles, especially in infants, susceptible to infection, which may manifest itself as acute infective bronchitis, bronchiolitis, or pneumonia. Sofoluwe described 98 children with bronchiolitis or bronchopneumonia in Lagos, Nigeria, who had been exposed for an average of over 3 hours/day to smoke from burning firewood (*7*). High concentrations of toxic gases were recorded in the smoke. Many of the children were on their mothers' backs or laps during cooking, and had been exposed to emissions from very early infancy. In a series of 132 infants with severe lower respiratory tract disease seen in South Africa, 93 (70%) had a history of heavy exposure to wood smoke from fires for cooking or heating (*8*).

The natural history of chronic obstructive pulmonary disease has been investigated among populations in Papua New Guinea. The highland groups in this cool, damp climate live in huts which are heated inside by open fires; the atmosphere is described as very smoky. Smoke density up to almost 5000 $\mu g/m^3$, aldehyde levels of up to 3.80 ppm, and carbon monoxide levels of up to 150 mg/m^3 were recorded (*9*). Recurrent respiratory infections, attributable to impaired pulmonary defence mechanisms, lead to chronic bronchitis and emphysema, and finally cor pulmonale (*10*). While studying chronic pulmonary disease in the eastern highlands of Papua New Guinea, Master (*11*) carried out complete physical examinations and took histories of 94 people of various ages. He found a high prevalence of abnormal pulmonary signs in all age groups and in both sexes; the highest prevalence was in the oldest and youngest groups. Although this prevalence was lower than among smokers, nonsmokers also had a high rate of abnormal pulmonary symptoms or signs. In assessing his work as well as the earlier studies in Papua New Guinea, Master (*11*) concluded that "the pathologic changes discovered suggest that air pollutants are the most important factor in the development of lung disease in New Guinea." In another study in Papua New Guinea, however, Anderson was not able to find a consistent relationship between differential woodsmoke exposures and respiratory distress symptoms (*12*). He worked with 112 Highland schoolchildren who were exposed to different levels of wood smoke. The 30-week surveillance revealed no significant difference in respiratory abnormalities or lung function.

In a study of 1788 cardiac cases admitted to Bir Hospital in Kathmandu, Nepal, Pandey & Ghimire (*13*) reported that cor pulmonale had a high incidence. Repeated respiratory infections early in life, cigarette smoking, and living in rooms made smoky by wood and cow-dung fires were identified as risk factors.

In a recent study, Pandey found a strong statistical correlation between the prevalence of chronic bronchitis and an index of domestic wood smoke among both smoking and non-smoking men and women. His study involved a population of about 3000 people in villages in Kathmandu valley. The statistical significance was high. His measure of exposure was the number of hours each person spent near the stove and was based on answers to a survey questionnaire (*28*). Ongoing studies by Pandey have shown a similar relationship between decay of lung function as measured by spirometry and hours per day near the stove for adult women smokers and a possible synergistic effect between wood and tobacco smoke.[d]

[d] PANDEY, M. R. ET AL. *Domestic smoke pollution and respiratory function in rural Nepal.* Paper presented at Third International Conference on Indoor Air Quality, Stockholm, 20-24 August 1984.

A high prevalence and high mortality rates from chronic cor pulmonale have been reported in India. The condition was at least as frequently seen among women as in men and occurred at younger ages than elsewhere reported; these findings are consistent with a causal relationship to chronic inhalation of smoke from cooking fires (*14, 15*). In northern and central India, chronic cor pulmonale accounted for 10–30% of hospital admissions, the highest rates of any non-industrial population in the world; males and females were about equally affected, in contrast to populations in industrial nations where the ratio of male:female prevalence rates is 5:1. Domestic air pollution is thought to be an important contributory cause of chronic cor pulmonale.[e]

The National Institute of Occupational Health in India surveyed 150 women who cooked with biomass fuels and 75 women who used kerosene (*16*). Medical examinations showed that the incidence of cough, cough with expectoration, and dyspnoea was considerably higher among women using traditional fuels. X-ray examinations revealed that respiratory abnormalities were more common among these women (18%) than in the control group using kerosene (5.8%). While no statistical information is available on the ophthalmological effects of the emissions, observations made during the general clinical examinations indicated that housewives exposed to dense smoke while cooking had general complaints of pain and watering in the eyes.

In rural Guatemala, carbon monoxide (CO) concentrations and carboxyhaemoglobin concentrations were recorded in 200 houses each in a low and a high altitude village. In the high altitude village where wood fires in huts without chimneys were ubiquitous (99% of the houses surveyed), CO concentrations averaged 35–45 mg/m^3 litre in poorly ventilated houses: women who were tested had carboxyhaemoglobin levels of more than 2% in the poorly ventilated houses (*17*). Such levels may have detrimental effects upon fetal growth during pregnancy.

Several ingredients of smoke from biomass combustion are actually or potentially carcinogenic. In the only study done to date of personal exposures using equipment actually worn by the women cooks rather than simply placed in the corner of the room (area sampling), Smith et al. (*18*) found average benzo[*a*]pyrene (BaP) exposures during the cooking period in four villages in western India to be nearly 4000 ng/m^3. This is a very large concentration by global standards. In terms of the amounts of BaP that would be inhaled, it is equivalent to smoking about 20 packs of cigarettes per day. The exposure to suspended particulate matter reached over 55 000 μg/m^3 and averaged about 7000 μg/m^3. This might be compared with the WHO recommended maximum 24-hour levels of 100–150 μg/m^3.

Aggarwal et al. (*19*) found similar levels in a study measuring the BaP and SPM concentrations near cooking stoves in Ahmedabad, India. This illustrates that many urban as well as rural houses in developing countries burn solid fuels in open stoves and thus can have high concentrations of harmful pollutants.

Given these levels of BaP and other carcinogens, it is hardly surprising that an association has been observed between certain upper respiratory system cancers and a history of exposure to biomass emissions. In Kenya, carcinoma of the nasopharynx (NPC) occurs more commonly among populations in the highlands where cooking is done indoors because of the cool damp climate than in populations in the hotter areas where food is cooked out of doors (*20*). The cool damp climate also forces children to stay indoors for much of the time. Indoor air samples from Kikuyu village huts in the high incidence area of Kenya had elevated concentrations of carcinogenic polyaromatic hydrocarbons, i.e., BaP and related chemicals (*21*).

Clifford (*22*) has reported great variations in NPC incidence and mortality rates in

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[e] *Prevention and control of pulmonary hypertension*. Report of an Inter-Country Seminar, New Delhi, 15-19 October 1979. Unpublished document WHO/SEA/CVD/26, 1980.

Table 6. Air quality inside 8 huts in Kenya at different altitudes

Altitude (metres)	Ethnic group	Tribe	Sample size[a]	Total particulate matter collected (mg)	Total organic matter extracted (mg)	Total organic matter (mg/m^3)	Benzo[a]-pyrene ($\mu g/1000\ m^3$)	Benz[a]-anthracene ($\mu g/1000\ m^3$)
> 3000	Nilo-Hamitic	Nandi	B	431.0	289.3	2.754	291	268
> 3000	Bantu	Kikuyu	A	731.2	632.0	6.763	166	515
< 3000	Nilo-Hamitic	Nandi	B	592.0	409.5	3.898	140	225
> 2000	Bantu	Kikuyu	A	252.4	240.6	2.575	85	79
< 2000	Nilo-Hamitic	Samburu	A	246.2	93.9	1.005	37	33
> Sea level	Bantu	Wadigo	A	140.2	75.5	0.808	24	29
Sea level	Bantu	Wadigo	A	57.7	41.1	0.440	12	15
Sea level	Bantu	Wadigo	B	33.0	31.9	0.304	None found	16

[a] Total sample size: A = 93.446 m^3 (3300 ft^3); B = 105.050 m^3 (3710 ft^3)
(Source: reference *22*).

relation to ethnic origin, living conditions, and concentration of total particulate matter, BaP and benz[*a*]anthracene in village hut air samples (Table 6). This establishes a prima facie case for a causal relationship. Other studies of NPC, however, showed no association with biomass smoke and indicated that other environmental and genetic factors may play a role (*29*).

A case-control study of lung cancer in women (200 cases, 200 controls) is in progress in Hong Kong. The possible relationship to inhaled emissions from cooking stoves has been examined in as yet unpublished analyses from this study. Koo (personal communication) found that there is a higher relative risk (2.21) of bronchial irritation among those with a past history of using wood-burning stoves than any other type of fuel. The relative risk for coal-burning stoves is 1.28. In other words, bronchial irritation is well over twice as frequent (121%) among those who have used wood-burning stoves, and 28% commoner among those who have used coal-burning stoves. The risk increases with duration of use. However, the numbers are small and a past history of use of several sorts of fuel is a confounding variable. Other epidemiological and indoor concentration studies are being conducted in China in rural areas where lung cancer rates in non-smoking women have been found to be elevated (*30*).

Other miscellaneous chronic disabilities may arise from the prolonged use of biomass fuels in poorly designed and situated cooking stoves in rural village huts. Opacity of the lens and other chronic disabling ocular lesions may result from repeated acute inflammatory conditions of the conjunctiva owing to the irritant effect of emissions. Anecdotal reports that refer explicitly to chronic eye irritation and raise the possibility of permanent damage to eyesight are common. An example is from Fiji (*23*) where women cooks complained that wood smoke from cooking fires caused sore, inflamed eyes. Unfortunately no clinical and epidemiological details are available on the severity and prevalence of the problem. The occurrence of trachoma in Fiji confuses the picture, making prevalence very difficult to determine anyway.

It is important to emphasize the fact that the health problems described in the above paragraphs, may not be at all representative of the true prevalence of health problems in these settings or in the world as a whole. Hospital-based case series especially are likely to be unrepresentative of community experience, particularly in rural communities of developing countries. This review of the health problems can only include information on what has been reported, as opposed to what may be present but unreported in the same (and in other) populations. In this respect, we are—as so often—seeing only the tips of icebergs.

It must be emphasized also that the victims of these health hazards are most likely to be women. Indeed, this is surely the largest occupational health problem for women in rural areas of developing countries. Their infants and children, if kept close to the cooking stove, are also at risk; and if the emissions include teratogenic and mutagenic substances, there is a further risk of birth defects. These are serious problems and may rival or exceed those that may be better known, such as those due to the arduous task of collecting firewood in many parts of the developing world, particularly in Africa.

EVALUATION AND SUMMARY OF STUDIES ON THE HEALTH EFFECTS

Biomass fuel emissions present a health hazard whose effects vary in type and severity depending on the local situation, the type of fuel used, and the population at risk. The culture, customs, and housing conditions of the people are important determinants of the level and nature of the risk. Climate and weather conditions also influence the exposure to biomass fuel emissions because people will spend more time indoors when it is cold and wet than when it is dry and sunny. The people affected will include infants and children as well as the women who do the cooking.

Under the broad heading of "culture" should be considered child-rearing practices. Are infants, for example, close to their mothers during cooking, or are they kept in a place far from the stove while their mothers prepare the meals? Are infants and small children encouraged to play out of doors or are they confined indoors for much of the time?

Under the heading of "customs" should be considered the type of meals prepared, the length of time required to prepare them, and the inclusion in the cooking ingredients of volatile oils and spices which may themselves produce irritant or toxic fumes. In addition, are these meals cooked on fires using only biomass fuel, or are other fuels sometimes used? Are exposures to cooking-fire smoke exacerbated by exposure to tobacco smoke?

The housing conditions of the population at risk may be the most important determinant of the impact on health from biomass combustion emissions. If the house is spacious, well-ventilated and has a flue or chimney to carry emissions to the exterior from the fire, the indoor air will be much less polluted than if there is inadequate ventilation and no flue or chimney.

The type of fuel is another variable that influences the risk to the exposed population. Clearly the risk is greater if, for instance, the fuel contains lead as a contaminant (*24*), or if there is an unusually high content of polyaromatic hydrocarbons in the smoke (*31*).

As discussed above, there are few systematic studies that have been directly addressed to the health effects of biomass combustion products in spite of the large population at risk. In compensation, however, it is possible to tentatively extrapolate from far more extensive studies of the health impacts of the same pollutants in other situations. The most valuable studies in this regard are those done in urban situations for exposure to SPM, occupational health studies of the impact of polycyclic aromatic hydrocarbons such as BaP, and the extensive literature on active and passive tobacco smoking and health. In many ways the mixture of pollutants and the extent of exposures for typical cigarette smokers are similar to those for cooks working over ventless biomass-burning stoves.[f]

An examination of the epidemiological literature indicates five major categories of ill-health that could be expected from high exposures to biomass combustion products. These

[f] SMITH, K. R. *Air pollutant emissions, concentrations and exposures from biomass combustion: the cigarette analogy*. Paper presented at the Annual Meeting of the American Chemical Society, Division of Fuel Chemistry, Philadelphia, PA, 1984.

are listed here along with the places where the rural studies mentioned above were carried out on these effects:[8]

(1) Chronic obstructive lung disease (Nepal, Papua New Guinea);

(2) Heart disease, particularly cor pulmonale caused by pulmonary damage (Nepal, India);

(3) Cancer, particularly of lung and nasopharynx (Indonesia, Kenya, Malaysia);

(4) Acute respiratory infections, particularly in children, due to degradation of the respiratory defence mechanisms (Africa, Papua New Guinea); and

(5) Low birth weights due to maternal exposures and associated with a range of perinatal and infant ill-health.

The existence of all these conditions, with one exception, is consistent with the available rural epidemiological data discussed previously. Indeed, WHO has now concluded that respiratory diseases are the chief causes of mortality in developing countries (*32*) and it is well recognized now that acute respiratory infections in children are a major cause of infant mortality in developing countries (*33*). Exposure to biomass combustion products may well play an important role in the etiology of both chronic and acute respiratory diseases. Lung and nasopharyngeal cancers, however, are not generally associated with rural areas of developing countries but with urbanization and industrial development in general.

At present the full dimensions of the health problems attributable to the use of biomass fuels can only be very roughly delineated. There is almost certainly appreciable premature death and widespread disability in virtually every country and culture where biomass is the predominant source of domestic energy.

In places without comprehensive, countrywide health information systems, systematic descriptive epidemiological studies would be valuable. In countries that do not have a comprehensive vital statistical or health information system but do have vital registration areas, some information may already be available but this has not been studied. Similarly, in those countries that have cancer registries covering defined populations (e.g., parts of India, Colombia, Nigeria), cases of upper and lower respiratory tract cancer could be identified for case-control studies.

There are many arguments for the speedy development and use of comprehensive health information systems, which would provide facts about the national, regional and local distribution (incidence rates, etc.) of symptoms, sicknesses, disabilities, visits to primary health care facilities, reasons for hospital admission, and causes of death (*25*).

RURAL DEVELOPMENT

Experience has shown that the most successful rural development efforts often have been those that rely on village participation both in setting priorities and in implementing programmes (*26*). There is no reason to believe that efforts to introduce improvements in fuels, stoves, or housing would be any different.

Because of the likely continuing role of biomass fuels and simple stoves for cooking and heating, it is useful to include considerations of smoke exposures along with the other priorities in rural development plans. In particular, this is important in that changes for reducing exposure can be made in conjunction with other programmes at relatively low cost. The experience and thinking behind present concepts of rural development are too extensive to be adequately discussed here. All that can be done is to illustrate some of the

[8] SMITH, K. R. ET AL. *Biomass combustion, air pollution and health: a global review*. East-West Resource System Institute, Honolulu, 1984 (Unpublished paper).

ways in which smoke exposures might interact.

A good example is provided by Bajracharya (*27*) in the description of his experience in several hill-region villages in Nepal. He played the role of a *lami* (Nepali word for matchmaker) to help match the perceived needs and priorities of the villagers with the requirements, capabilities, and constraints of outside aid agencies. In one village, the villagers chose improved stoves as the most attractive of several alternatives offered to them. Although the stoves were advertised mostly on the basis of being more efficient, it turned out in practice that the villagers were pleased with them primarily because of the reduction in smoke exposure. Indeed, they disagreed as to the true efficiency of the stoves in actual use.

This experience leads to two conclusions. First, it shows the importance of attending to the perceived needs of the villagers, not only to better fit the proposed innovation into the physical and social environment that must eventually absorb it, but also to actively engage the people in these innovations so that the villagers have a stake in their success. Secondly, the experience illustrates that it is not always possible to know in advance precisely how a group of people are going to respond.

One of the most promising technologies for reducing exposure is the "smokeless" cooking stove. Much field work is needed, however, to determine the effectiveness of different designs. In their study of personal exposures, Smith et al. (*18*) found that there was only a slight decrease in exposures received by women cooking on a particular variety of improved stoves with flues that had been introduced in the area. This indicates the need to have follow-up studies on these stoves to make sure that they actually operate in homes in the same manner as they did in the laboratory.

In addition to changing the fuel or the stove, another option for reducing air pollutant levels is to improve the ventilation where the fuel is being used. The easiest solution in principle would be to move the cooking activity outdoors and for the stove to be located downwind from the cook or other persons nearby. Climatic conditions, such as heat, cold, wind, and rain, can make this approach impractical for much of the year. In addition, village social conditions, such as interference by village animals, may be part of the reason why cooking is done indoors in the first place. The need for privacy, or other cultural reasons, may also be obstacles to moving the cooking activity outdoors. Nevertheless, cooking is done outdoors, or in very well-ventilated covered kitchen houses or verandahs in many parts of the world. Such practices could be encouraged to spread. Clearly, such a recommendation would not be possible in cold upland areas.

While the main focus is on the damage that smoke from cooking stoves inflicts on health, there is a belief among some people that in some situations smoke helps to preserve health and property. An often-mentioned benefit of smoke is its use as a mosquito repellent. By having a smoky cooking fire in the house, mosquitos are kept at bay temporarily, although they will return when the smoke clears. The actual reduction in risk of contracting malaria and other mosquito-born diseases as a result of this practice is not known. It is conceivable though that to some householders the advantage of a mosquito-free environment is greater than the nuisance that the smoke represents.

Siwatibau (*23*) observes that "the fire improves and strengthens the thatching on a Fijian bure (traditional thatched home) through constant drying." Three respondents in the Indian (Gujarat) study also mentioned this benefit of having smoke in the house. A similar observation has been noted in Nepal (*27*). Smoke from cooking and heating fires may, indeed, discourage termites and other pests in thatched roofs. Apart from the radical solution of replacing thatching with pest-resistant material such as tiles or metal sheets, a compromise may be to build a smoky fire periodically for the express purpose of "smoking" or fumigating the house. Thorough fumigation at regular intervals might do as much to preserve building materials as daily smoky cooking fires.

THE ROLE OF WOMEN

In recent years, there has been a rising interest in WHO programmes that focus on the role and condition of women. This is somewhat different from the many past programmes dealing with, for example, maternal and child health, in that the recent emphasis is on women's roles including (but not limited to) their role as mothers. The need for economic and political power, for example, is part of this new orientation. In general, it does seem that women are probably the largest single disadvantaged class among the rural poor, who as a whole are disadvantaged relative to most other groups.

Women also seem to be the principal sufferers from smoky fires in most cultures because of their role as family cook. It is therefore likely that women are the group best able to put the benefits and discomfort of smoke exposures into context. This implies that women must become active participants in rural development decisions related to stoves, fuels, housing, and other smoke-related issues if these perceptions are to be weighed in the process of bringing about improvements.

In a small survey of the women in four villages in western India where air pollution monitoring was undertaken,[h] the women generally responded that they wanted to be rid of the smoke (75%) but, at the same time, most (85%) said that they had done nothing about it on their own. It could be that the women felt that the smoke was not a significant enough problem to warrant any action. This would not seem to be supported by the high percentage who associated ill health (85%) or unwanted dirtiness (35%) with the smoke, and the relatively low proportion (28%) who noted any benefits from the smoke (as mosquito repellant or for thatch preservation). It could also be, however, that the women felt that they were unable to make any changes because they either did not have the necessary authority or the necessary knowledge, or both.

PUBLIC HEALTH AND MEDICAL CARE

A better understanding of biomass smoke exposure patterns and resultant direct and synergistic impacts might have implications for the provision of medical care and the objectives of public health programmes. Clearly, for example, there would be profound implications if it was found that rural lung cancer is more prevalent than has usually been thought or that lung cancer rates could be expected to rise as people began to live longer, as a result of control of other diseases. The association of smoke exposures with acute respiratory diseases of early childhood is also of interest to public health programmes since both medical diagnosis and treatment, especially in rural areas, for a range of lung conditions could be performed more effectively if the impacts of past and present exposures to smoke were known. The determination of priorities among areas for receiving scarce medical care and public health resources might therefore take into account the estimates of smoke exposures as well as other regional characteristics.

In addition to priorities in the provision of medical care, these investigations would be valuable for selecting areas that should have first access to programmes designed to implement smokeless stoves or upgraded fuels. Indeed, if smoke exposures were eventually found to have a significant impact on rural health, changes in fuels, stoves, ventilation, housing, and cooking patterns may well be appropriately linked to other efforts in primary health care. Such efforts may be much more effective, socially and financially, than increased expenditures on secondary and tertiary medical care.

[h] RAMAKRISHNA, J. & SMITH, K. R. *Smoke from cooking fires: a case for participation of rural women in developmental planning*. Document WP-82-20, Resource Systems Institute, East-West Center, Honolulu, 1982.

ACTION NEEDED

Better assessment of the problem

The present inadequate knowledge of the problem must be expanded in several ways. Information is needed about types of fuel used, types of stoves, and cooking practices in those parts of the world where a health hazard from biomass fuel emissions is known or suspected. Primary health care workers at rural or village level could gather this information as part of their routine duties, thus providing quite quickly an appraisal of the current situation. This information ought to be related to information about social customs and child-rearing practices to determine whether only the persons cooking, or the cooks plus their infants, or the entire households are potentially at risk.

Health problems attributable to pollution from biomass fuels have hardly been properly identified, let alone studied in any systematic fashion. The same approach employed in studying any other health problem is appropriate for investigating this constellation of problems: namely, through clinical observations, laboratory experiments, and epidemiological investigations. However, owing to the time required by such an approach higher priority may be given to making immediate interventions aimed at reducing adverse health impacts.

Epidemiological surveillance using vital and health statistics data that are already available in a number of countries could provide estimates of the burden of ill health due to chronic obstructive pulmonary disease, in terms of the age, sex and geographical distribution, which by inference could throw some light on the relationship of this disease to indoor air pollution caused by biomass fuel emissions. Where resources are available, case–control studies could also be done to confirm that indoor air pollution is a cause of chronic obstructive pulmonary disease and nasopharyngeal cancer.

Improvement in the utilization of biomass fuels

The reduction of these health hazards should be pursued through the development of cooking stoves with improved combustion efficiency coupled with reduced smoke emissions. Pilot demonstrations should be carried out to ensure that the stoves truly perform as stated, under local conditions, and that they are acceptable to the user. Every effort should also be made to avoid transferring the indoor pollution to outdoors, although initially this may be unavoidable.

Further research should be carried out on procedures to measure the composition of wood smoke produced by primitive combustion facilities in developing countries. Special attention should be paid to the relationship between the amount of naturally occurring hydrocarbons in wood and the corresponding levels of polycyclic aromatic hydrocarbons in smoke.

A more long-term solution should be sought through the development of cleaner sources of energy such as charcoal, biogas, or vegetable oils, which is becoming urgent because of the current fuelwood crisis.

Public awareness programme

A rural information and training project should be initiated immediately. The purpose of this project would be to disseminate information and increase awareness among rural populations (village women in particular) in the developing countries about the health risks associated with indoor smoke. The project would provide information on simple ways for alleviating the problem as well as give guidance on more long-term solutions.

As a last point, the problem of adverse health effects stemming from biomass fuel combustion is complex and widespread. As outlined in this report, the problem has many facets including rural community development, energy, housing, health, etc. For this reason, a concerted effort of international cooperation among the various concerned international agencies is required to provide solutions and relief in time.

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